Research Area Overview

Development, Manufacturing and Applications of Fiber Reinforced Polymer (FRP) Composite Materials

CFC

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Constructed Facilities Center (CFC)

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Recent Research Activities at CFC

- **Advances in composite and hybrid materials for high volume applications such as structural components;**
- **Value-added, high volume product development; utilizing recycled engineering polymers;**
- **Manufacturing methods with industry;**
- **Nondestructive evaluation techniques and tools;**
- **Technology transfer in coop. with industry and government agencies.**

General R& D Objectives:

- **To foster and conduct R & D vital to the rehabilitation of our nation's constructed facilities**
- **To promote and advance FRP composites for civil infrastructure applications**

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Fiber Reinforced Polymer (FRP) Composites

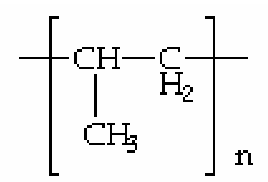
- **R&D Objective**

  To develop and implement continuous and chopped fiber reinforced composites for structural components and systems with better strength, serviceability, durability and cost-effectiveness

- **FRP Design**
  - Fabric reinforcements (Glass, Carbon, Aramid, PP)
  - Resin / Matrix (Thermoplastics and thermosets)

Thermoplastic Resins

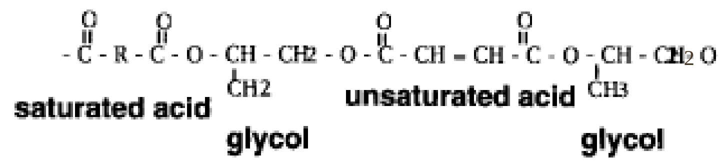
- **Characteristics:**
  - **Soften, melt and flow upon heating, e.g., HDPE, PP, PC, ABS**
- **Advantages:**
  - **Unlimited shelf life**
  - **Easy to handle (no tackiness)**
  - **Recyclable**
  - **Postformable**
  - **Higher fracture toughness than epoxy**
- **Disadvantages:**
  - **Lower creep resistance than thermosets**
  - **High viscosity ~ 1,000,000 cP**



PP

Thermoset Resins

- **Characteristics:**
  - **Liquid resin gets cured into crosslinked network structure that will not melt upon reheating, e.g.** Polyester, Epoxy, Vinyl ester, Urethane, Phenolics
- **Advantages:**
  - **Lower resin viscosity (~20 – 500cP)**
  - **Better fiber wet-out**
  - **Better creep resistance**
  - **Excellent thermal stability after cure**



Polyester

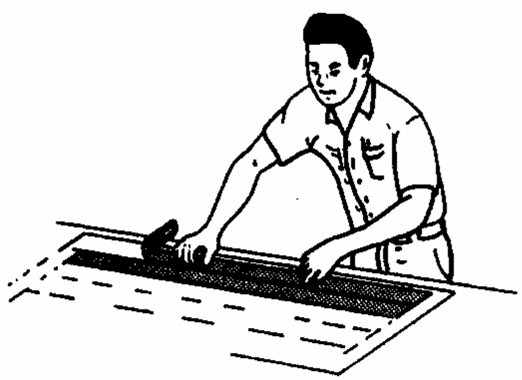
- **Disadvantages:**
  - **Brittle (low strain-at-break)**
  - **Limited storage life at room temperature**
  - **Non-recyclable via standard techniques**
  - **Molding in the shape of a final part**

Manufacturing Methods for FRP Composites

- Hand lay-up
- Compression molding
- Pultrusion
- Resin transfer molding
- Injection molding
- Filament winding

Hand Lay-up

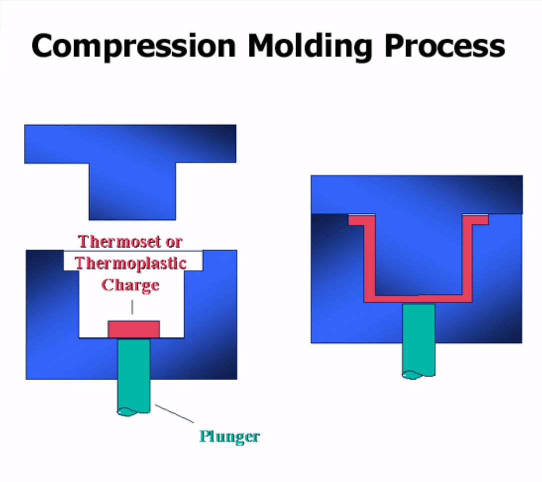
- **A manual fabrication process. It involves building up layers of chopped glass or woven glass mat impregnated with catalyzed resin around a suitable mold. The reinforcement is then rolled for better wet-out and removing trapped air.**



<u>Used for</u>

- **large diameter structure;**
- **custom shapes like asymmetric shapes;**
- **bonding two or more modules.**

Compression Molding



For thermosets or thermoplastics. The process consisting of placing a charge in the mold, which is subsequently closed and held at a high pressure, and then heating the mold to initiate cure reaction.

Available with CFC:

PHI hydraulic presses with electrically heated platens and water cooling

- 30 and 50 ton capacity
- Platen size: 12.5"x18.5"
- Max mold temp: 315 ^{0}C
- Two-stage hydraulic pump

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Pultrusion Process

A highly automated production process that continuously draws resin-impregnated fiber reinforcements, at speeds ranging from 1 to 5 feet per minute, through a heated die which forms and cures to the desired cross-section with no part length limitation. Pultrusion produces:

- high strength structural shapes
- with High volume reinforcements
- at moderate tooling and capital equipment cost.

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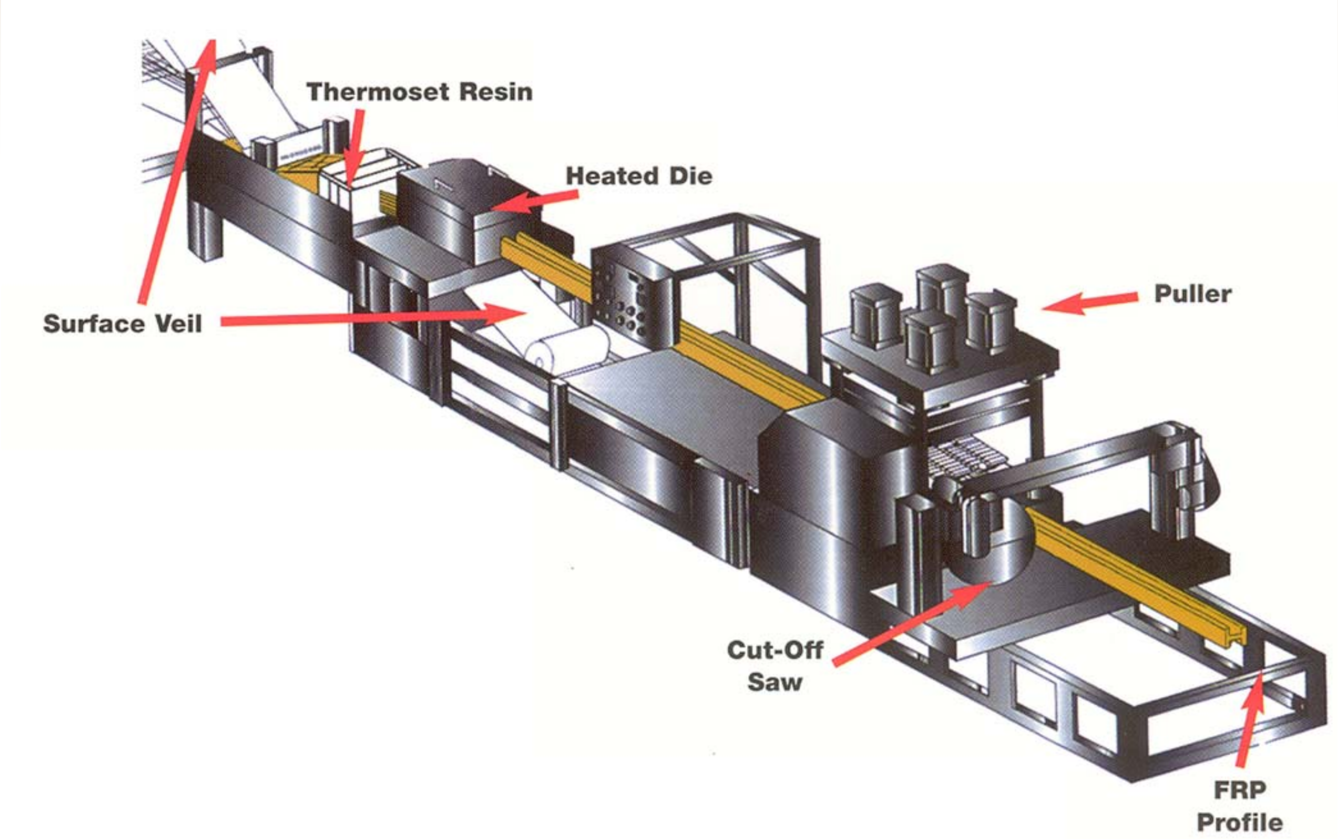
Pultrusion Machine



Available with CFC:

A resin-injected pultrusion process is under development at CFC in cooperation with industry.

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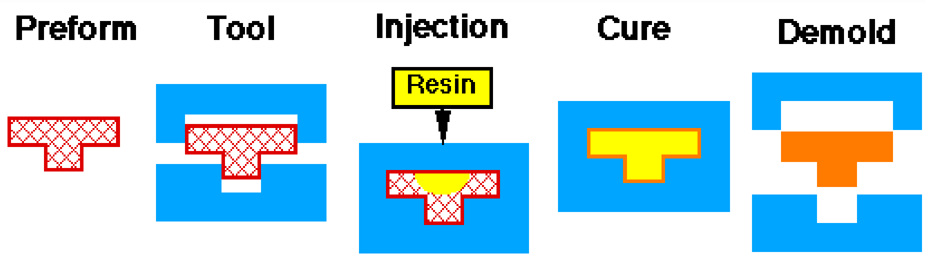
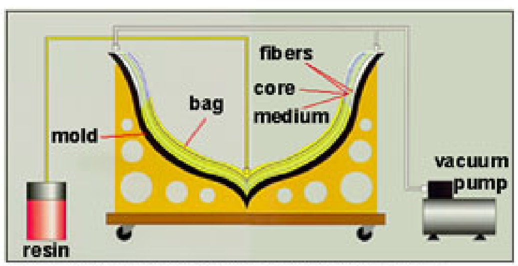
Resin Transfer Molding Process



SCRIMP SYSTEM SCHEMATICS



source illustration from Hardcore DuPont Composites

Boat Hull Manufacture

- Process developed and patented by Seamann's Composites
- Single-sided tooling
- Injection achieved through high-permeability surface layer to cause through-the-thickness flow

- Vacuum-Assisted Resin Transfer Molding (VARTM)
- Seeman's Composite Resin Injection Molding Process (SCRIMP)
  - Hybrid of VARTM and Vacuum bagging
  - One-sided tooling
  - Large-scale parts
  - Low void content

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Resin Transfer Molding Machine

Available with CFC:

Plastech Megaject Sprint RTM

- **MPG mold protection guard**
- **Vacuum assisted infusion**
- **Automatic control**
- **Output 150g - 6kg/min**
- **Mix Ratio- 0.5% - 4.5%**
- **Tool w. electric heater**

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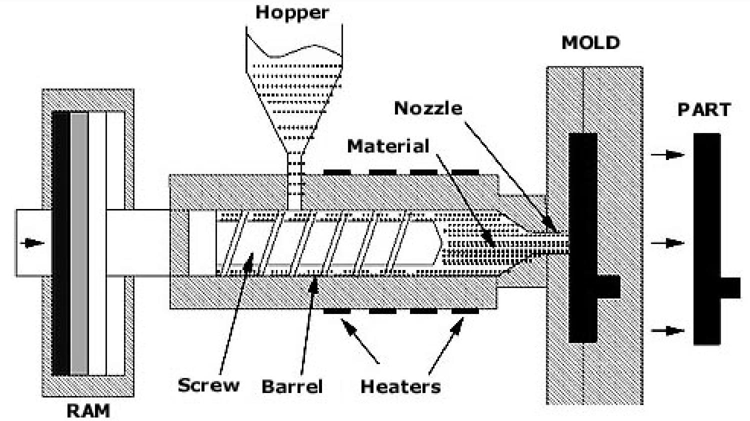
Injection Molding



For thermoplastic resins commonly with short glass fibers as reinforcements. No chemical reaction occurs during the molding process.

Available with CFC:

Battenfeld BA 1000/315 CDC with B4 controls

-Clamp force (US tons) 110
-Tie bar distance (in)16.54 x 16.54
-Screw diameter (in) 1.18 and 1.77
-Injection capacity (oz)3.6 and 8.17
-Wear resistant barrel / screw sets
-High speed injection

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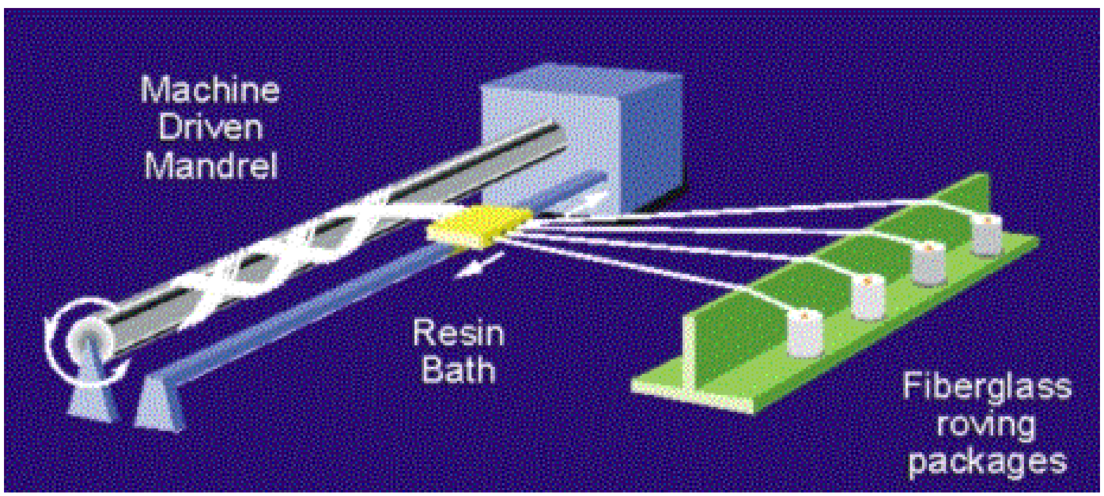
Filament Winding

- A process where continuous fiber filaments called rovings, are saturated with catalyzed resin and helically wound around a mandrel. The fibers are fed through a device which moves up and down the length of rotating mandrel.
  - High fiber-to-resin ratio (high strength-to-weight ratio)



- CFC is developing high volume products using filament winding at WVU and thru interactions with industry.
- Available with FMW Composite Systems Inc in Bridgeport, WV.

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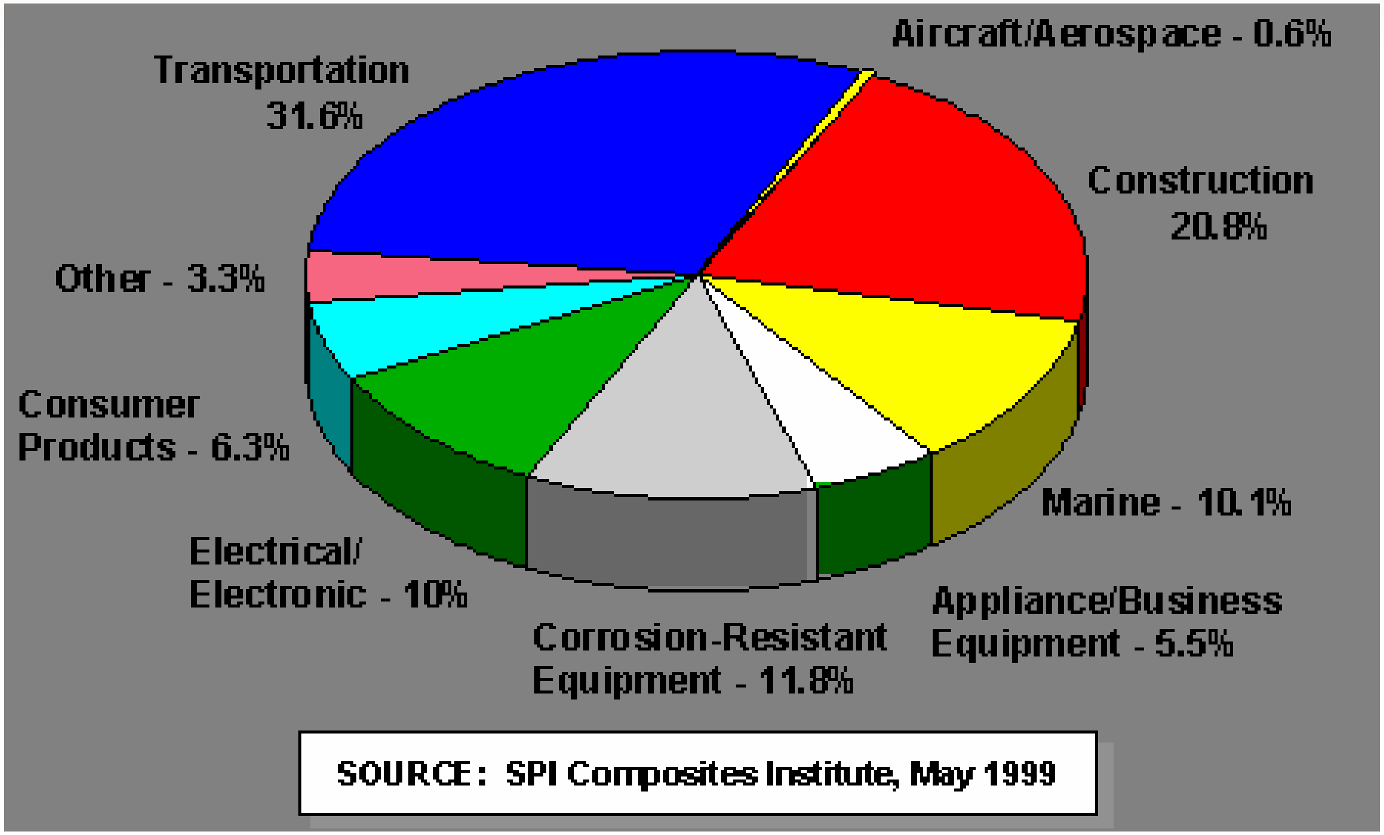
Markets and Applications



U.S. FRP composites: 3.59 billion pounds in 1998

FRP Composite Structural Components

- FRP Rebars
- FRP Beams
- FRP Column Wraps
- FRP Tension Members
- FRP Laminates
- FRP Bridge Decks

<u>Top</u>: Katy Truss bridge, Marion Co, WV
<u>Bottom</u>: Martha Queen's bridge, Lewis Co, WV

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FRP Composite Bridges

- FRP bridge deck
- FRP stringers
- FRP abutment panels
- FRP rebars for concrete bridge decks, parapets, retaining structures
- Strengthening of steel girders using carbon laminates

Top: FRP deck over beams, Laurel Lick Bridge, Lewis Co, WV
Middle: Deck GFRP rebar, McKinleyville bridge, Brooks Co, WV
Bottom: GFRP in abutment, Martha Queen's, Lewis Co, WV

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GFRP Reinforcements for Pavements

- FRP reinforcement including FRP dowel bars for concrete pavements
- Reinforcing asphalt pavements using FRP grids
- Polymer concrete wearing surface

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FRP Composites in Highway Structures

- FRP sign boards and posts
- FRP guardrail system
- FRP sound barriers
- FRP drainage systems (pipes, culverts)

- Composite building - FRP panels and shapes

FRP Composites for Structural Rehabilitation

- Rehabilitation of concrete bridge components using FRP wraps
- Replacement of deteriorated bridge truss members using FRP shapes

WV Preston Co. Muddy Creek bridge

Carbon wrap concrete beam

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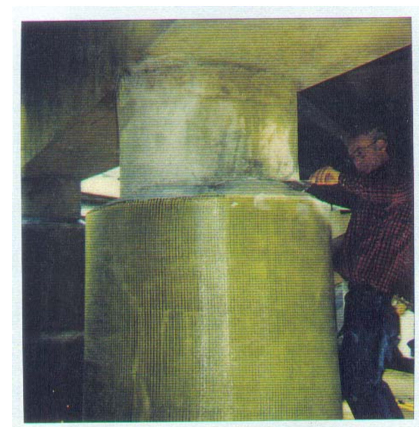
FRP Wrapping (Wet Lay-up) of Structural Members

Left: GFRP wrapped rail road tie.
Right top: GFRP wrapped guide rail post.
Right bottom: Piers with GFRP wrap, Pond Creek Bridge, Wood County, WV



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FRP Rehabilitation of Railroad Bridge 568, Moorefield, WV

Rehabilitation includes (1) wrapping the pile cap together with the piles using GFRP fabrics to prevent the timber cap from dropping off the piles due to flood debris and (2) repairing a decayed pile using GFRP fabric and resin/hardener filler.

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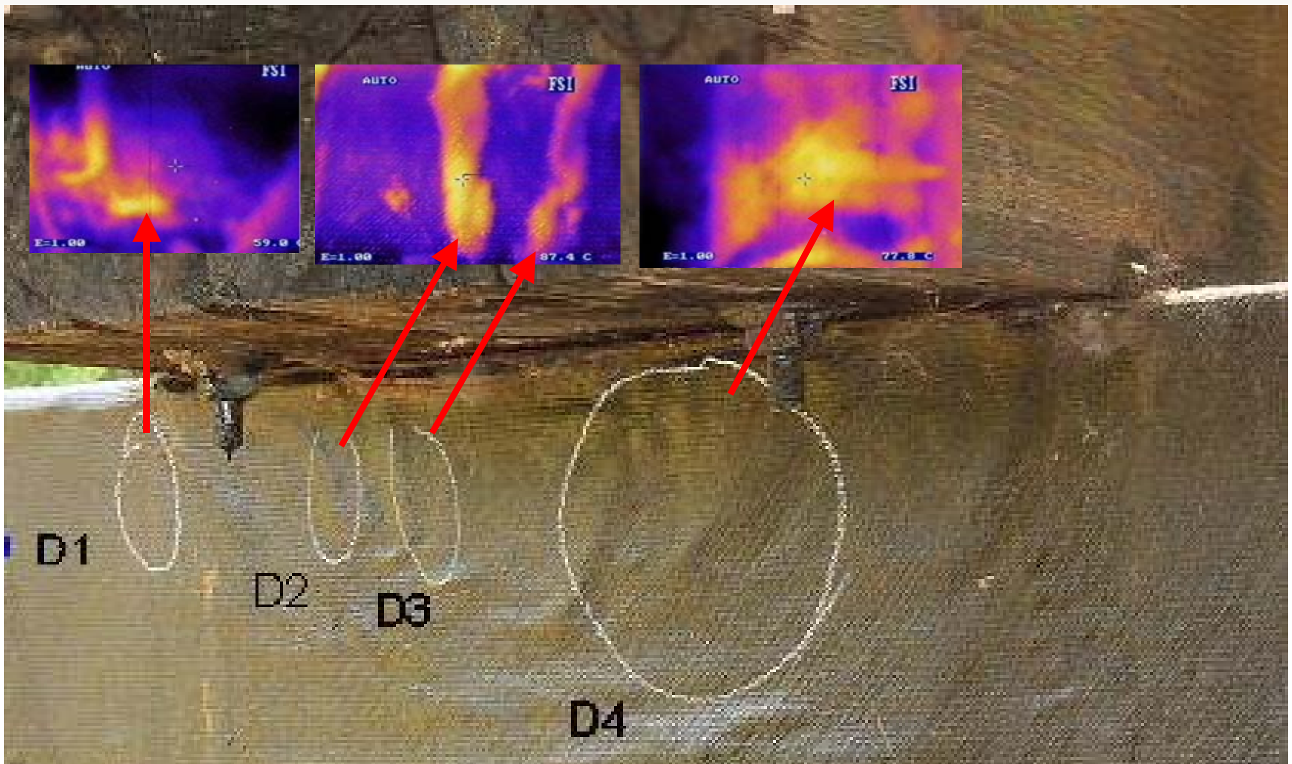
Static & Dynamic Testing and Evaluation of Rehabilitated Members



D1 & D4 – Detected by Tap Testing & IR Thermography

D2 & D3 – Detected by IR Thermography **Only**

Bridge 568 – IR Thermography testing of wrapped pile cap

(Samer Petro et al 2002)

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Utility Poles

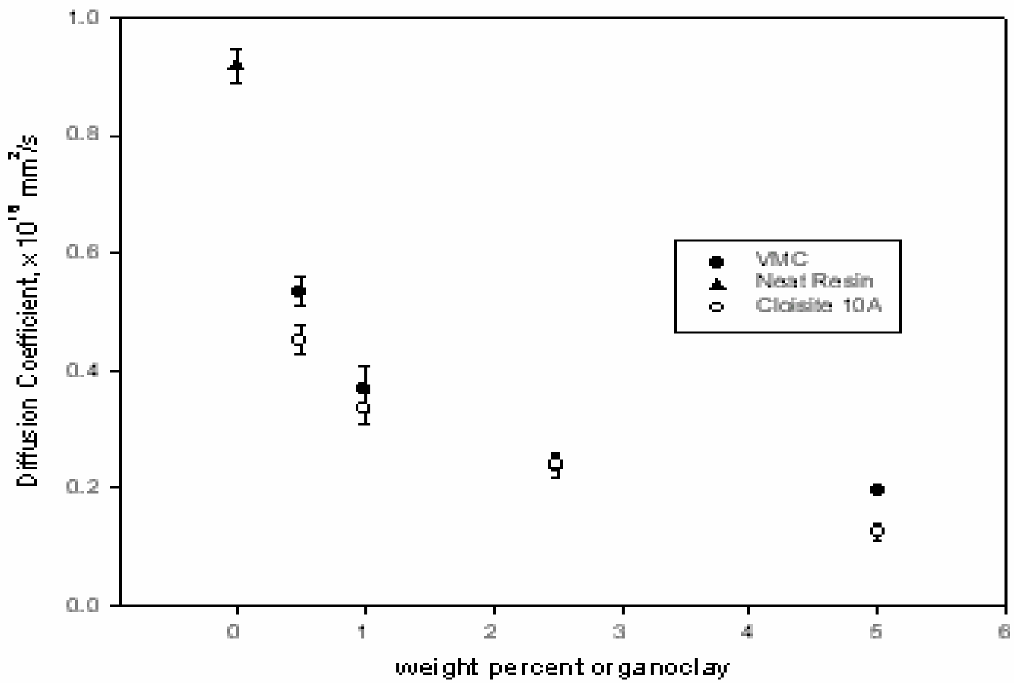
- 130 million utility poles in-service in USA
  - 98% chemically treated wood poles
  - ~4 million poles need replacement per year
  - ~90,000 poles in WV
- $4 billion treated wood poles annually
  - $2.8 billion for replacement
  - $1.2 billion for new construction

FRP Poles

	Conventional materials*			Existing FRP composite poles**			Proposed FRP composite poles		
	40' long Class 4 Cedar wood pole	40' long Class 4 steel pole	40' long Class 4 concrete pole	40' long Class 4 FRP pole	40' long Class 1 FRP pole	80' long Class 1 FRP pole	40' long Class 4 FRP pole	40' long Class 1 FRP pole	80' long Class 1 FRP pole
ANSI O5.1 Cantilever load, lbs	2400	2400	2400	2400	4500	4500	2400	4500	4500
Weight, lbs	~900	~600	~3000	~415	~600	~1350	~200-225	~250-300	~800-900
Cost, $	~300+35	~370	~350	~900	~1500	~4000	~450-500	~650-700	~2500-3000
Lifespan, years	~30-40	~80	~80	~80	~80	~80	~100	~100	~100

* Data from Feldman & Shistar, 1997. Penta treated Cedar wood pole has a maintenance cost of $35 per pole.
** Data from Shakespeare Product Datasheets and Strongwell Ebert Product Information.

Vinyl Ester / Clay Nanocomposites for Improved Durability



Moisture diffusion coefficient as a function of clay loading
(Shah, Gupta and GangaRao, 2002)

Vinyl Ester Urethane Heteropolymeric Resin for Improved Performance

Mechanical properties of carbon reinforced pultruded profiles

ILLS: Interlaminar shear strength, reflecting the adhesion of fiber/matrix;
Fatigue test: three point bending for one million cycles **(Klumperman, 2002).**

	Flexural strength, MPa	Flexural modulus, GPa	ILLS, MPa	Fatigue strength, MPa	Fatigue strength, %
Vinyl ester resin	1200	110	42	860	72
Vinyl ester -urethane heteropolymeric resin	1570	115	86	1180	80
Epoxy	1400	110	80	1100	80

Carbon fiber reinforced vinyl ester urethane heteropolymeric resin as an alternative to epoxy-carbon composite systems

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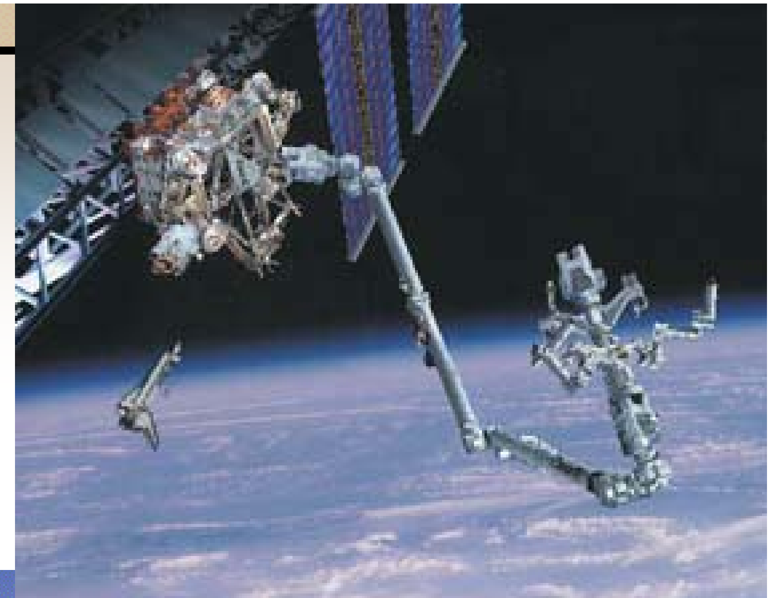
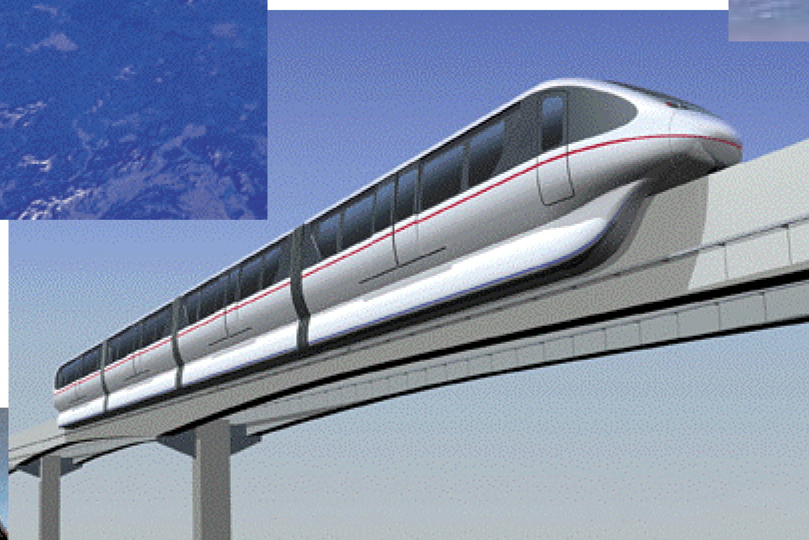
New Applications





Technology Transfer Programs

- Conferences on Polymer Composites organized by CFC (1992; 1996; 1999; 2001; 2004)
- Short Courses to industry engineers
- Technology Transfer Programs through WVDOT, USDOT, FHWA, and other agencies
- Hands-on Training (on our facility) to small manufacturers
- Training graduate and undergraduate students
- Presentations and Seminars at conferences
- Development of manuals and specifications for inspection

What CFC Offers

- Technology Training
- New Product Development
- Material Characterization
- Structural Evaluation
- Field Monitoring
- Design and Prototype Manufacturing of Polymer, Composite and Hybrid Materials